

Letters to the Editor

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On the Production Process of Mesons

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ACCORDING to present cosmic-ray evidence, it seems that mesons are produced in the upper atmosphere by the primary cosmic radiation, which consists presumably of protons. The cross section for this production is of the order of nuclear dimensions since the primary radiation is absorbed in about 1-m water equivalent of air. The mesons are presumably produced in showers of several particles. Very much smaller cross sections, however, are found for any interaction of the mesons themselves with matter. After being produced in the first 100 g/cm² of the atmosphere, a considerable fraction of the mesons are able to penetrate through the total atmosphere and even deep underground. The only interaction with matter seems to be the one which is caused by its charge. Scattering by interactions other than electric is small and perhaps non-existent. Recent experiments have shown that even the absorption of slow mesons by nuclei takes place with a probability far below the expected one.

Nordheim and Hebb have shown that these facts are in contradiction with any simple theoretical description of meson production.¹ One should expect a similar cross section for processes induced by mesons as for processes in which mesons are created. This result follows immediately from any "interaction term" which is introduced into the Hamiltonian in order to describe the meson creation, if one applies the well-known principle of detailed balancing. This difficulty has been repeatedly emphasized by Oppenheimer.²

The striking lack of reversibility suggests the possibility that the process of meson creation is not elementary, but consists of a succession of several elementary processes. The total process will not be reversible if one of the successive steps is much slower than the initial one. The following analogy may perhaps clarify the picture: The cross section for the production of fission in uranium by a nuclear particle is of the same order as the cross section for the fission fragments to collide with another fragment, in accordance with the reversibility of the fission process. Let us imagine, for the sake of argument, however, that the fission fragments were not observable and that the only known effect would be the absorption of a nuclear particle by uranium with the subsequent emission of several electrons due to the beta-disintegrations of the fragments. We would

then be faced with an analogous lack of reversibility, since the absorption of electrons by nuclei is extremely weak.

A number of possible combinations of processes suggest themselves for the mechanism of meson production. One could assume that the primary cosmic radiation transforms the nucleons into an "excited" state which, after a time long compared to the excitation process, decays with the emission of several mesons. The relatively long life-time of the "meson-pregnant" state would give rise to the small interaction between mesons and nucleons. Another alternative assumption, which was proposed by R. E. Marshak, would be that the primary radiation produces a number of particles which are mesons of a different kind than the ones observed. They have a limited lifetime after which they decay into the actual mesons observed. The lifetime could be long enough to preclude a strong interaction between the observed mesons and the nuclei.

These examples are meant only to exemplify the type of concepts which one may be forced to introduce into our description of meson production to understand the apparent lack of reversibility. The ideas expressed in this note were suggested by the discussions at the Theoretical Physics Conference on Shelter Island, June 2 to 4, 1947, sponsored by the National Academy of Sciences.

¹ L. Nordheim and M. Hebb, *Phys. Rev.* **56**, 494 (1939).

² Lecture delivered at the New York meeting of the American Physical Society, Shelter Island Conference, 1947.

The Thermal Diffusion Constant of Helium and the Separation of He³ by Thermal Diffusion

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WE have been investigating the possibility of separating He³ by thermal diffusion, and as part of the preliminary work we have constructed a hot wire column using a platinum wire 0.018 cm in radius. The radius of the water-cooled outer wall was 0.436 cm and the length 305 cm. The power consumption for a wire temperature of 780°C was 1520 watts and the operating pressure 10 atmospheres. Well helium flowed continuously past the lower end of the column at a sufficient rate so that the concentration here could be considered to have its normal value,¹ 1.6×10^{-7} . As the relaxation time for the above conditions would be of the order of 10⁴ years, a linear increase in concentration is observed with time and with a negligible draw-off of gas it was possible to produce an enrichment in He³ of 860 times in a period of 8 days.

During the course of our experiments it was possible to accumulate 52 cm³ at N-P of well helium in which a He³ enrichment of 300 times had been achieved. The He³ concentration was sufficient to permit accurate mass-spectrometer analyses and hence a determination of α , the thermal diffusion constant, by the two-bulb method employed in this laboratory² for other gases. With the hot and cold bulbs at temperatures of 340° and 0°C, respectively, α was found to have a value of 0.059 ± 0.005 . This value is considerably lower than 0.076 tentatively assumed by Jones

and Furry³ in their design of a separating plant for He³. Employing our value of α and using Jones' and Furry's theory for column performance, one would predict a 125-fold concentration rise per day as compared with the 108 actually observed. In view of the difficulty of the measurements this may be considered as satisfactory agreement.

From the work of Atkins, Bastick, and Ibbs⁴ on thermal diffusion in binary mixtures of rare gases, one would predict a higher value of α in helium than we have found. With the same apparatus as was used for the helium α -determination, we have made a rough determination of the thermal diffusion effect in a helium-neon mixture and found a lower value than that given by the above investigators and in excellent agreement with the new work on binary gas mixtures by Grew.⁵

This work was assisted by Navy Contract N5ori-147, T.O. III, between the Office of Naval Research and the University of Minnesota.

¹ L. T. Aldrich and A. O. Nier, Phys. Rev. **70**, 983 (1946); H. A. Fairbank, C. T. Lane, L. T. Aldrich, and A. O. Nier, Phys. Rev. **71**, 911 (1947).

² A. O. Nier, Phys. Rev. **56**, 1009 (1939); **57**, 338 (1940); L. G. Stier, Phys. Rev. **62**, 548 (1942).

³ R. C. Jones and W. H. Furry, Rev. Mod. Phys. **18**, 151 (1946).

⁴ B. E. Atkins, R. E. Bastick, and T. L. Ibbs, Proc. Roy. Soc. **A172**, 142 (1939).

⁵ K. E. Grew, Proc. Roy. Soc. **A189**, 403 (1947).

A Random-Absorption Effect in Diffraction of X-Rays from Coarse Powders

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CONSIDERING the statistical distribution and sizes of the grains and voids in a powder sample, the x-ray absorption factor for a given path length in the sample will have a statistical distribution. The average absorption factor obtained in this manner is in general different from the absorption factor obtained by using the average absorption coefficient. The resulting modification of the diffracted x-ray intensities will be referred to as the random absorption effect.

Although it is quite simple to set up the differential equation for the intensity of diffracted radiation, an exact solution of the equation is, in general, not possible. An approximation can be readily obtained, however, as will be demonstrated presently.

Consider a powder of a single substance. This case, besides being simple to handle, is of special interest because the "micro-absorption" effect discussed in a paper by Brindley¹ is zero for this case. The path of a ray penetrating a portion of the sample will be made up of a succession of elementary lengths occurring alternately in the solid material and voids. Let the representative path length between discontinuities be designated by D . Considering diffraction from an opaque powder block as used conventionally in the Geiger-counter x-ray spectrometer, let the sample be divided up into elementary slabs of thickness $D \sin \theta$ as indicated in Fig. 1, θ being the Bragg angle. The contribution to the integrated intensity from the n th slab is given by:

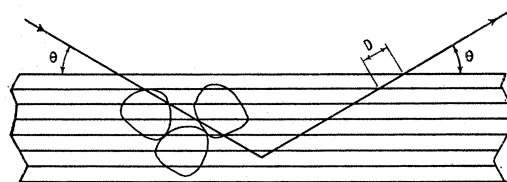


FIG. 1. Relationship of x-ray beam to sample. Several particles are sketched in to illustrate the approximate relationship of particle diameter to D and the thickness of an elementary slab.

TABLE I. Measurements on random absorption effect of x-rays.

| Powder size (10^{-4} cm) | μD | $(P/P_0)_{\text{exp}}$ | $(P/P_0)_{\text{theo}}$ |
|--------------------------------|---------|------------------------|-------------------------|
| 10 to 20 | 0.43 | 0.94 | 0.91 |
| 20 to 44 | 0.92 | 0.81 | 0.82 |

$$P_n = (\text{Integrated intensity due to a single slab}) \times (\text{Absorption of the beam in the preceding slabs})$$

$$= \frac{JAv}{\sin \theta} \left\{ \int_0^D \sin \theta \exp\left(\frac{-2\mu x}{\sin \theta}\right) dx \right\} \times \{v \exp(-\mu D) + v_0\}^{2(n-1)}, \quad (1)$$

where J = integrated intensity per unit volume of the solid material on basis of no absorption, A = cross section area of the x-ray beam at the sample, μ = linear absorption coefficient of the solid material, v = fraction of the volume occupied by solid material, $v_0 = 1 - v$ = fraction of the volume occupied by voids.

For a solid block, the integrated intensity is $P_0 = JA/2\mu$.

The value of P for the powder block is $\sum_{n=1}^{n=\infty} P_n$. Hence, one obtains

$$P/P_0 = [1 + \exp(-\mu D)] / [2 - v\{1 - \exp(-\mu D)\}]. \quad (2)$$

An analogous expression for any number of crystalline components can be obtained in a similar manner. It is interesting to note that Eq. (2) gives the correct value of unity for $D=0$ (very fine powder) and for $v=1$ (solid block).

An experimental check was made on the random absorption effect. Three samples of iron were used: (a) solid block, (b) particles ranging from 10 to 20 microns in diameter, (c) particles ranging from 20 to 44 microns in diameter. In the theoretical evaluation of P/P_0 by Eq. (2), approximate values of D for samples (b) and (c) were taken to be 7.5 and 16 microns, respectively, and a value of 0.5 was assumed² for v . Radiation from an iron target was employed in a Geiger-counter x-ray spectrometer. The results are given in Table I:

These results indicate that a random absorption effect is present, and its order of magnitude is given by Eq. (2).

A more complete and detailed discussion of theoretical and experimental results is being prepared for publication.

¹ G. W. Brindley, Phil. Mag. **36**, 347 (1945).

² This value is quite reasonable according to experiments on compaction of powders. See for instance, M. Muskat, *Flow of Homogeneous Fluids Through Porous Media* (McGraw-Hill Book Company, Inc., New York, 1937), p. 13.